ULTRA-REFRACTORY CALCIUM-ALUMINUM-RICH INCLUSION IN AN AOA IN CR CHONDRITE YAMATO-793261. M. Komatsu[1,2], T. J. Fagan[2], A. Yamaguchi[1,3], T. Mikouchi[4], M. Yasutake[1,3], and M. E. Zolensky[5], [1]SOKENDAI, Graduate University for Advanced Studies, Kanagawa, Japan (komatsu_mutsumi@soken.ac.jp), [2]Dept. Earth Sciences, Waseda University, Japan, [3]National Institute of Polar Research, Japan, [4]Dept. Earth and Planetary Science, University of Tokyo, Japan, [5]ARES, NASA Johnson Space Center, Houston, USA.

Introduction: CR chondrites are a group of primitive carbonaceous chondrites that preserve nebular records of the formation conditions of their components [e.g., 1;2]. We have been investigating a set of Antarctic CR chondrites from the Japanese-NIPR collection in order to study variations within this group. During our study, we have found an AOA that encloses an ultrarefractory (UR) CAI in Yamato-793261 (Y-793261). UR CAIs are rare in carbonaceous chondrites [e.g., 3], and only three UR CAIs in AOAs have been identified so far [3-5]. UR CAIs can provide information on crystallization processes at very high temperatures in the solar nebula. Here we describe the petrology of Y-793261, and preliminary results on this newly discovered AOA enclosing a UR CAI.

Methods: A polished thin section of Y-793261 was studied using SEM, EPMA, and Raman spectroscopy. Petrology and Raman characteristics are also compared to those from other CR chondrites and the primitive CO chondrite Y-81020, as listed in Table 1.

Imaging, mineral identification and quantitative analyses were performed using a JEOL JSM-7100F FE-SEM and JEOL JXA8200 EPMA at NIPR. Our Zr analyses may have been affected by an interference of Sc on Zr Lα. We plan to determine the magnitude of this interference in future work, but the ZrO_2 data reported here are uncorrected and should be considered preliminary. Raman spectra were collected using a JASCO NRS-1000 Raman Spectrometer at NIPR. Raman analytical parameters were similar to those of [6].

Results and Discussion:

Petrography of Y-793261

CR chondrite Y-793261 is composed of chondrules, AOAs, CAIs, mineral fragments, and matrix. AOAs and CAIs are more abundant in Y-793261 than in other CR chondrites we have examined; eight AOAs are present in the Y-793261 thin section, whereas the other CR thin sections have only 0 to 2 AOAs (Table 1).

Previous work has shown that aqueous alteration in CR chondrites causes (1) variable replacement of metallic Fe-Ni by magnetite or sulfide and (2) formation of phyllosilicates along edges, fractures and twin boundaries of olivine and pyroxene [11]. In Y-793261, phyllosilicates occur in matrix and around some chondrules, but are rare inside chondrules. The minimal alteration of mafic phenocrysts suggests that Y-793261 is similar to weakly altered petrologic types 2.6-2.5 described in [11].

Maturation grade of organic material in Y-793261

Raman spectra were collected on randomly-selected matrix areas in thin sections. Raman spectra from CR chondrites in this study exhibit first-order carbon D- and G-bands at ~1350 and ~1600 cm^{-1} respectively.

[4], [12] and [13] showed that I_d/I_g increases in petrologic type from 3.0 to 3.7 in CO/CV and unequilibrated ordinary chondrites (UOCs). Because the compositions of organic matter in CR and CV/CO are similar, Raman parameters can be used for interclass comparison to compare their metamorphic grades. The spectra collected for this study from CR chondrites including Y-793261 all show relatively low I_d/I_g, suggesting low thermal maturity, particularly in comparison with matured UOCs and CV chondrites (P.T.>3.6) (Fig. 1).

High temperature signature of AOA:

Eight AOAs are found in the thin section of Y-793261. All AOAs in Y-793261 show little evidence for secondary aqueous alteration or thermal alteration.

AOA #4 consists mostly of fine-grained olivine, which often encloses segregations of Al-diopside and anorthite in a texture typical of AOAs (Fig. 2c). In one of these segregations, Al-diopside is in contact with Sc-rich pyroxene and a Zr-rich phase, similar to Sc-Zr-rich phases observed previously in UR CAIs [e.g., 3]. The UR inclusion has a concentric texture with a Zr,Sc-rich pyroxene core surrounded by Sc-rich pyroxene.

Refractory high-Ca pyroxenes in AOA #4 contain 17-36 wt.% Al_2O_3 and 6-10 wt.% TiO_2. The high Al-contents suggest that tiny inclusions of corundum or another Al-rich phase may be present. Concentrations of Sc_2O_3 and ZrO_2 (uncorrected for possible interference) vary between 2 and 8 wt.% and are positively correlated, increasing from core to rim (Fig. 3a). These Sc_2O_3 and ZrO_2 concentrations in pyroxene are intermediate between higher and lower values identified in previous studies of several UR CAIs [3] (Fig. 3). Pyroxene from UR CAI *3N-24* from oxidized CV chondrite NWA 3118 has a range of ZrO_2 concentrations similar to that of AOA #4, but with lower Sc_2O_3 [3] (Fig. 3b). The presence of the UR inclusion indicates that condensation of AOA #4 started at higher temperature than other AOAs in CR chondrites.

Enrichment of SiO_2 at lower temperature:

AOA #4 also contains ~5 μm sized, nearly pure SiO_2 grains with low-Ca pyroxene grains (Fig. 2d). It is not

clear whether the SiO_2 is crystalline or amorphous. In previous studies, pod-like SiO_2 grains were found in the chondrule margins in CR chondrite PCA 91082 [15]. [16] found that many Type I chondrules in CR chondrites contain silica-rich igneous rims (SIR), and suggested that SIR are formed either by gas-solid condensation onto chondrule surfaces and subsequent incomplete melting, or by direct condensation of $SiO_{(v)}$ into chondrule melts.

We have not observed SiO_2 grains in AOAs prior to this study. SiO_2 grains in AOA #4 occur with low-Ca pyroxene, suggesting formation at temperatures below typical olivine condensation temperatures [17]. AOA #4 in Y-793261 apparently preserves evidence of condensation at unusually high temperature (indicated by the UR CAI), combined with low-T interaction with gas (indicated by SiO_2 + low-Ca pyroxene).

References: [1] Weisberg M. K. et al. (1993) *GCA*, *57*, 1567-1586. [2] Krot A.N. et al. (2002) *MaPS*, *37*, 1451-1490. [3] Ivanova M. A. et al. (2012) *MaPS* 47, 2107-2127. [4] Ma C. et al. (2011) *MaPS*, 46, *suppl*, A144. [5] Noonan A.F. et al. (1977) *Meteoritics*, 12, 332-335. [6] Bonal. L. et al. (2006) *GCA*, 70,1849-1863. [7] Kojima H. and Yamaguchi A. (2005) *Meteorite Newsletter*, *NIPR*. [8] Schrader D. et al. (2011) *GCA*, *75*, 308-325. [9] Davidson J. et al. (2014) *MaPS*, *49*, 1456-1474. [10] Fukushima H. (2016) *Masters Thesis*, *Waseda University*. [11] Harju E.R. et al. (2014) *GCA*, 139, 267-292. [12] Quirico E. et al. (2003) *MaPS*, *38*, 795-881. [13] Bonal L. et al. (2007) *GCA*, 71, 1605-1623. [14] El Goersy A. et al. (2002) *GCA*, 66, 1459-1491. [15] Noguchi T. et al. (1995) *Proc. NIPR Symp.*, 8, 33-62. [16] Krot A.N. et al. (2004) *MaPS*, 39,1931-1955. [17] Krot A.N. et al. (2004) *GCA*, 68,1293-1941.

Table 1. Samples used in this study.

Name	Type	No. of AOAs[a]
Y-793261	CR2	8
Y-790112	CR2	not observed
Y-793495	CR2	not observed
Y-8449	CR2	not observed
Y-792518	CR2	not observed
A-881595	CR2(ungrouped C3?)[b]	2
Y-81020	CO3.0	37[c]

[a]Number of AOAs found in one thin section. [b]A-881595 was originally classified as a CR2 chondrite [7], but re-classification as an ungrouped C3 has been suggested [8,9]. [C]Unpublished data from [10].

➔ Fig. 3. ...from Efremovka, *HIB-11* from Murchison, *OSCAR* from Ornans [3 and references therein].

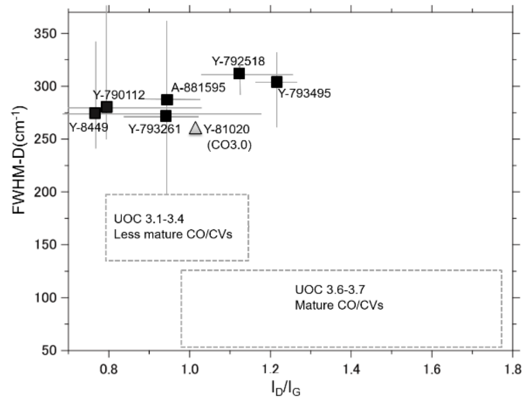

Fig.1. Spectral parameters of Raman bands of OMs in CR chondrites and Y-81020 in this study (after [4,13]).

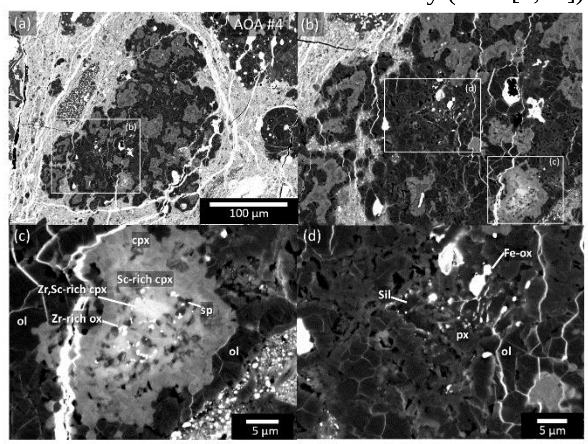

Fig. 2. BSE images of AOA #4. ol=olivine, cpx=high-Ca pyroxene, sp=slinel, Zr-rich ph=Zr-rich phase, Zr, Sc-rich cpx=Zr, Sc-rich high Ca pyroxene, Sc, Al-rich cpx=Sc, Al-rich Ca pyroxene.

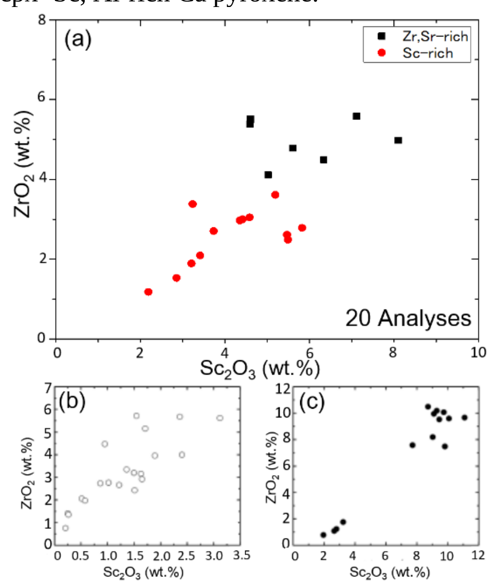

Fig. 3. Uncorrected ZrO_2 and Sc_2O_3 in pyroxene in UR CAIs from (a) AOA #4 (this study), (b) UR CAI *3N-24* from CV_{ox} chondrite NWA 3118 [3] and (c) *33E-1*